# Designing an optimal ensemble strategy for GMAO S2S forecast system

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## Why do we need new ensembles for Subseasonal-to-Seasonal forecasts?

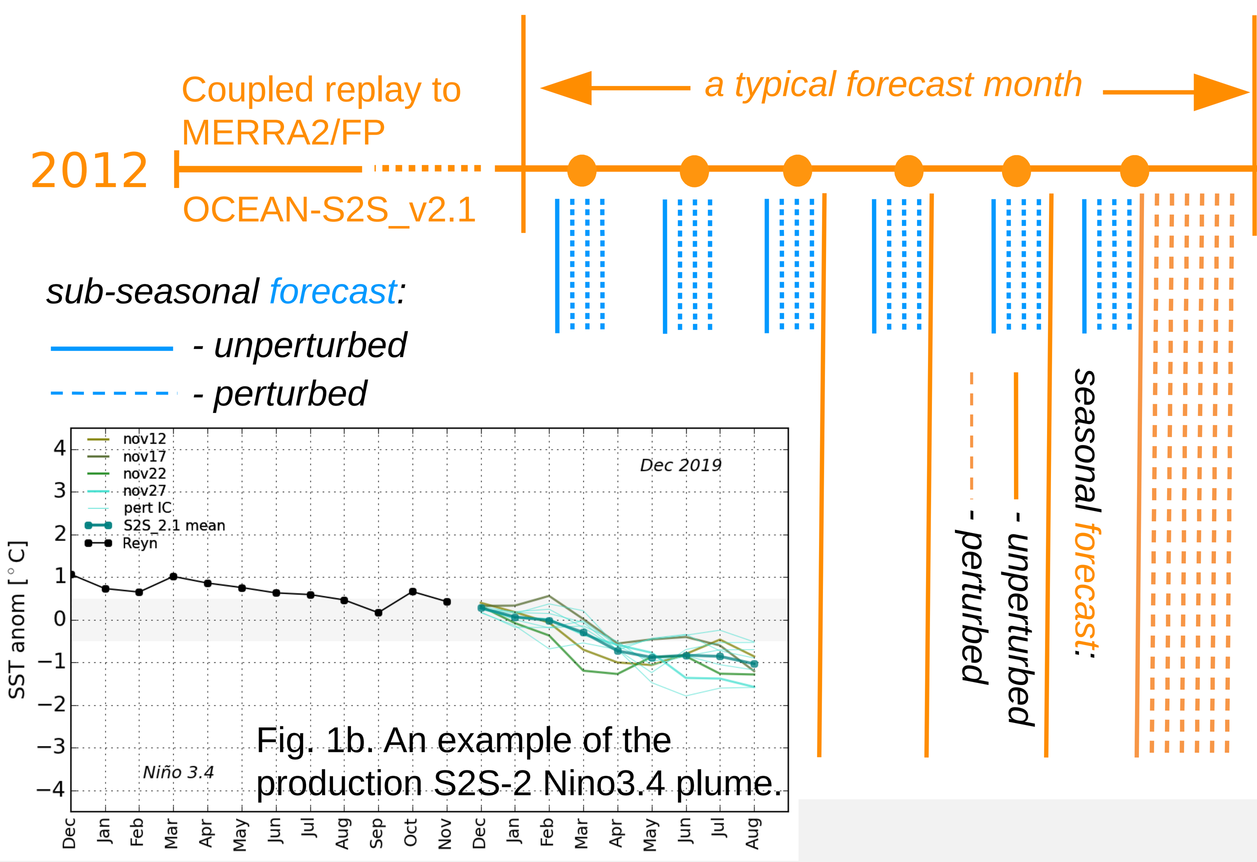



Fig. 1a. Schematic of the production S2S-2 forecast system. S2S-1 (2012-2017) had a similar setup, with the exception of subseasonal forecasts, which were not done at that time.

Fig. 1b. An example of the production S2S-2 Nino3.4 plume.

**Current production S2S-2 system features:**

- Lag/burst setup similar to S2S-1.
- Separate sub-seasonal and seasonal forecast
- Rigid procedure for generating perturbations for initial conditions, based on scaled differences of states separated by 5(1) days for seasonal(subseasonal) forecasts.

## Learning from S2S-1 and S2S-2

### Is the ensemble spread an indicator of forecast uncertainty?

*Let SDy* be the standard deviation of the observation *(y)*, $cor_{xy}^2$ the squared correlation between the ensemble mean forecast *(x)* and the observation, *σ the* standard deviation of the intra-ensemble spread, then

$$SEE = SDy\sqrt{1 - cor_{xy}^2}$$

and *R = σ/SEE*, which should be close to 1 for a perfect model:

if *R < 1* the model is under dispersive
if *R > 1* model is over dispersive

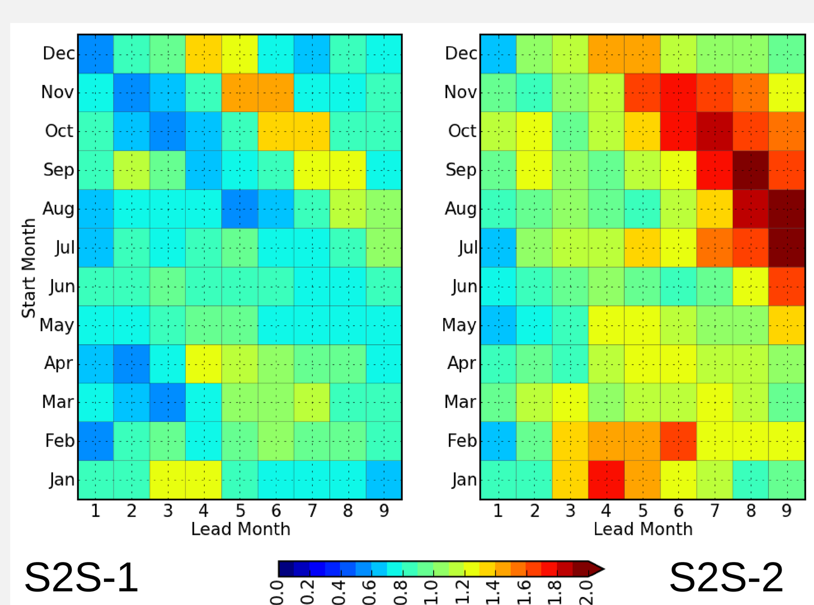



Fig. 2. *R* for both forecast system versions for for Niño3.4 SST, all initial months, all leads.

## Ensemble design for S2S-3

*Motivation:*

- For ENSO improve the under-dispersion at short lead time; control the over-dispersion at long leads.
- For sub-seasonal teleconnections improve the ensemble mean skill by increasing ensemble size.

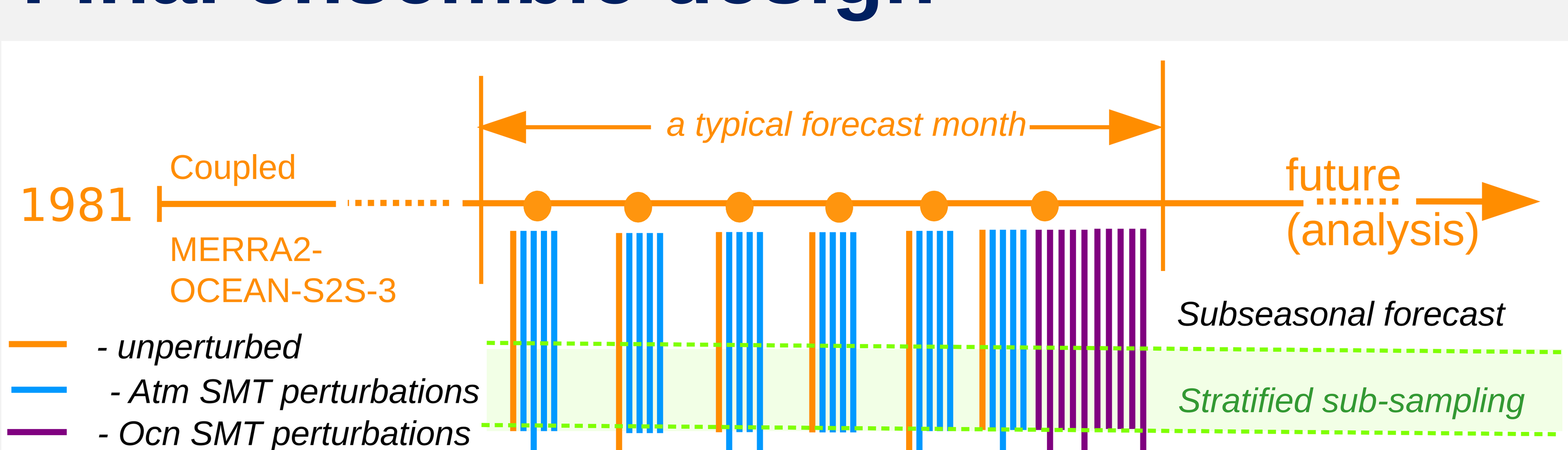
*Explore ideas for GEOS S2S-3:*

- The various patterns (eigenvectors) of perturbations and scaling.
- Different combinations of lag and burst.
- Use large ensemble for season-long forecasts, then sub-sample and continue with fewer members for the long-range forecasts.

*Methods:*

- Bursts of forecasts on a single date using initial conditions perturbations, generated from instantaneous states from coupled analysis at varying separations. Synchronized Multiple Time-lagged (SMT) approach.
- Stratified sampling to select ensemble members for long range forecast.

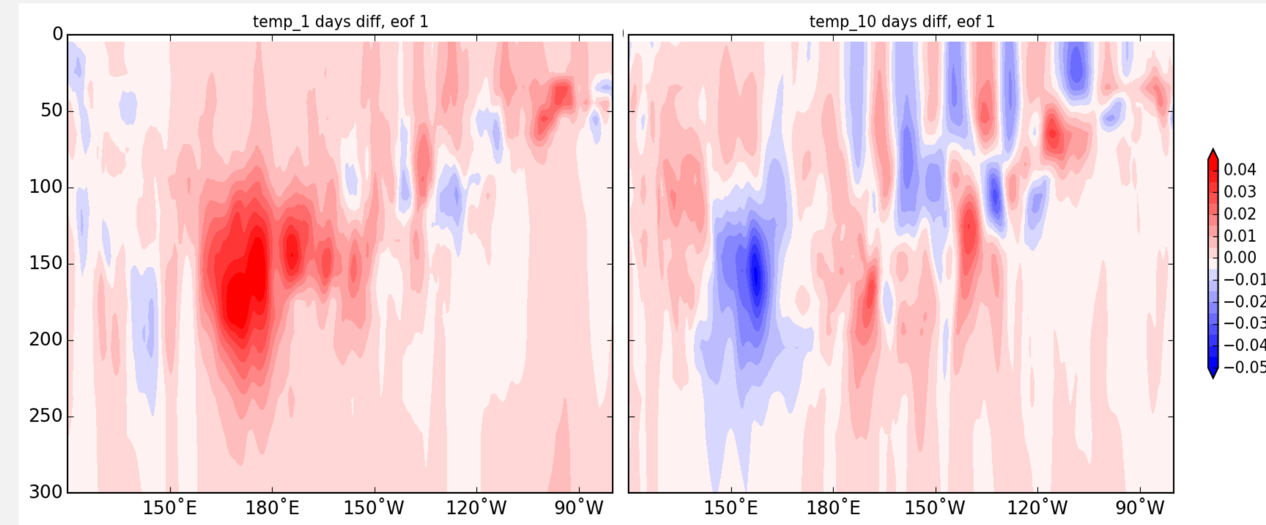
## Final ensemble design




This strategy is in the final testing stage for S2S-3, which will be frozen in early 2020 and released to the public later that year.

Fig. 7. Schematic of the S2S-3 unified sub-seasonal and seasonal forecast system design.

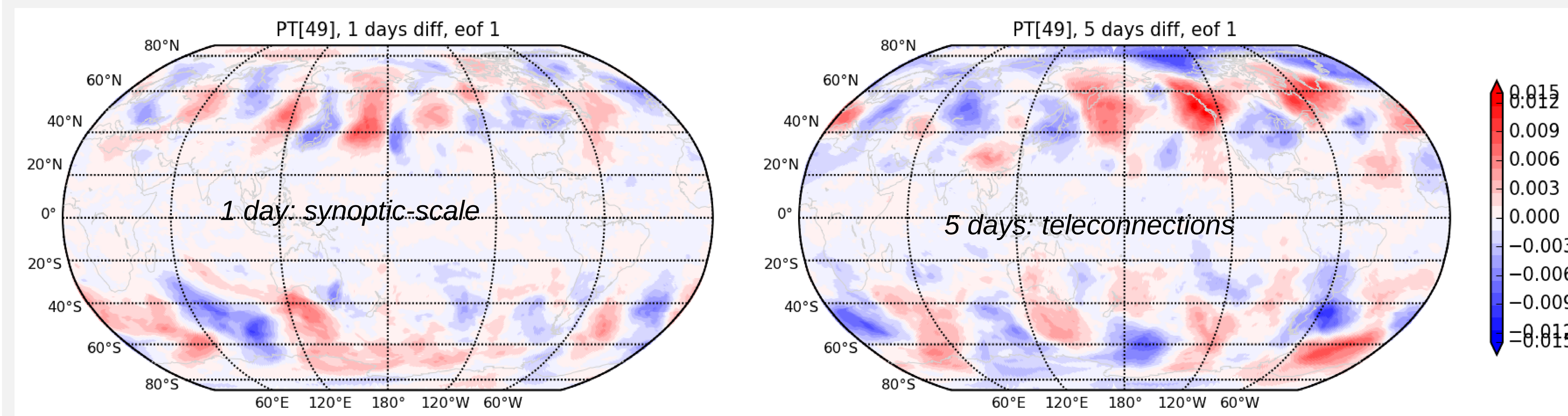
## Spatial patterns of perturbations. Span all scales.




By varying the separation time between nearby analysis states we are able to generate a wide array of different types of atmospheric and oceanic perturbations that represent physically realistic and important modes of variability.

Fig. 3a. EOF 1 of T(EQ) for 1 and 10 days separation.1 day: variations in the thermocline. 10 days: vertically-coherent wave-type variability.

Fig.3b. EOF 1 of Potential Temperature (500mb) for 1 and 5 days separation.




Scaling. To make the perturbations amplitude a small fraction (10% of STD) of the natural variability and independent of the separation, we produced an average set of scaling factors that vary only with season and states separation for ocean and atmosphere variables.

## Testing various types and combinations of lag/burst.

current S2S lag: 4 dates
current S2S burst: 6 mem
atm burst: 40 mem
ocn burst: 40 mem
lag: 30 dates mean drift

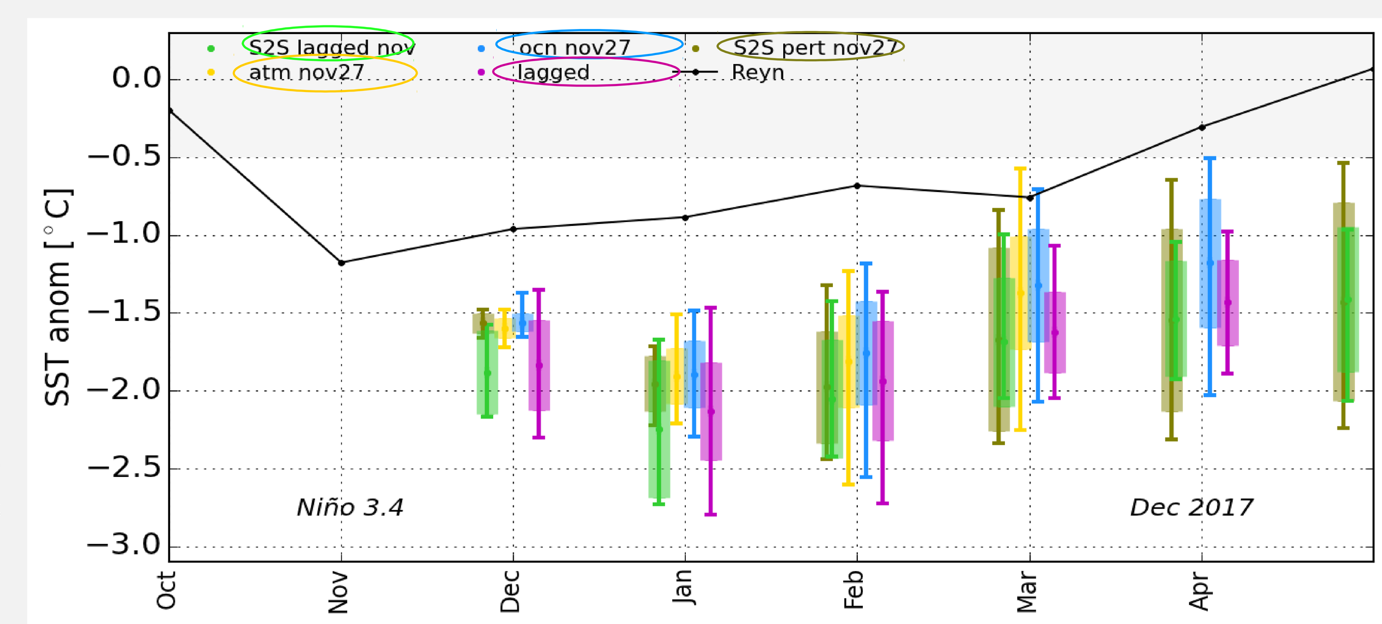



Fig.4.A case study comparison of various strategies for producing initial ensemble members: impact on ensemble spread shown as box and whisker plots where the whiskers denote the *max* and *min* values and the box has length equal to 2 standard deviations centered on the ensemble mean.

## Stratified sampling. KMEANS. Quantifying the results.

We take advantage of the information about the early error growth that can be obtained from the relatively large initial ensemble, in a way that ensures that we capture the leading directions (in phase space) of error growth. This can be especially important when the ensemble is characterized by more than one dominant direction of error growth.

The population of size *N* is divided into *L* disjoint strata, where $n_h(N_h)$ are the number of members of the sample (population) in stratum *h*. Each stratum is sampled in proportion to its representation in the population.

Performing the stratification very early in the forecasts emphasizes the variance structure of the initial perturbations, and those structures are not well maintained as the forecasts evolve beyond the first month.

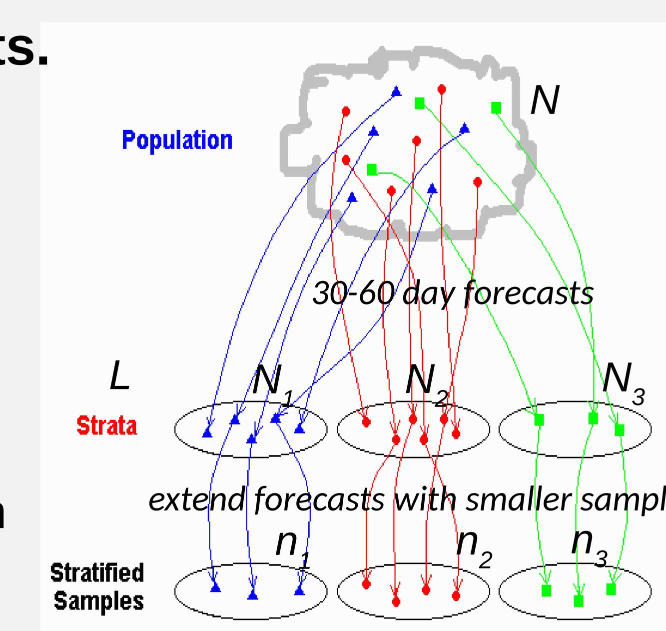
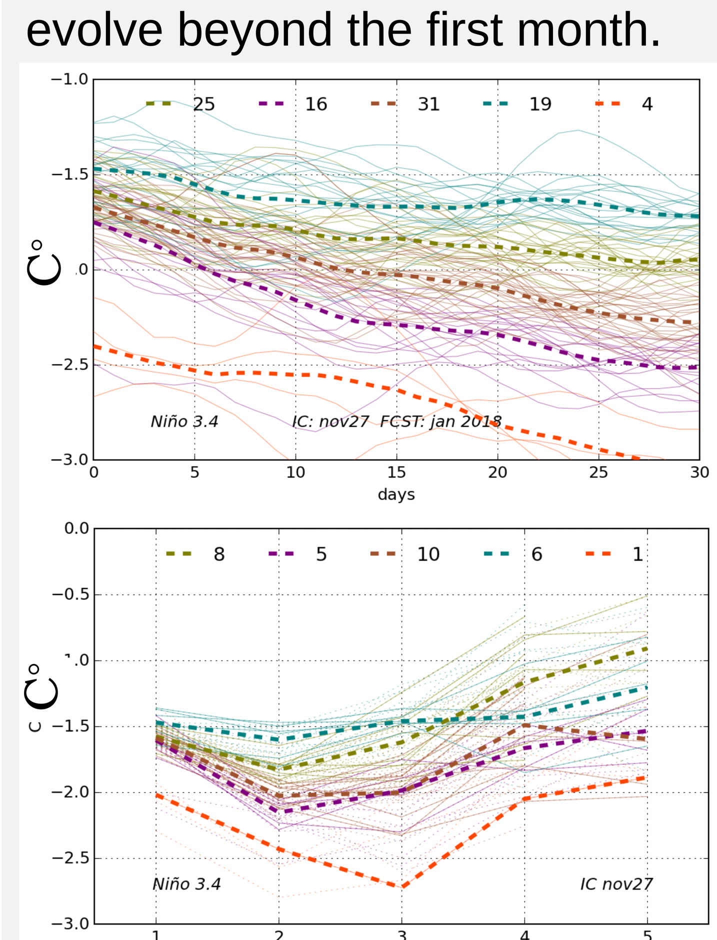



Fig. 5a. Schematic illustrating clustering procedure. Here the number of clusters is *L=3* with $N_1$, $N_2$ and $N_3$ their respective populations sampled down to $n_1$, $n_2$ and $n_3$.




By the second month the clusters are more likely to reflect the uncertainties associated with the underlying dynamical evolution of the climate system, which are maintained much longer into the forecast.

We use Monte Carlo approach (with 1000 random seeds) to estimate the means of the randomly sub-sampled and stratified smaller ensembles, and the variances $y_r$ and $y_s$ of these estimates.

Fig. 5b. Sub-sampling EXAMPLE.
Top: Daily Niño 3.4 index values, original clusters and means.
Bottom: Monthly values, extended forecast, solid lines are the sub-samples ensemble members, dashed – all the original members, thick dashed lines – cluster means. The envelope of the original ensemble is well spanned.

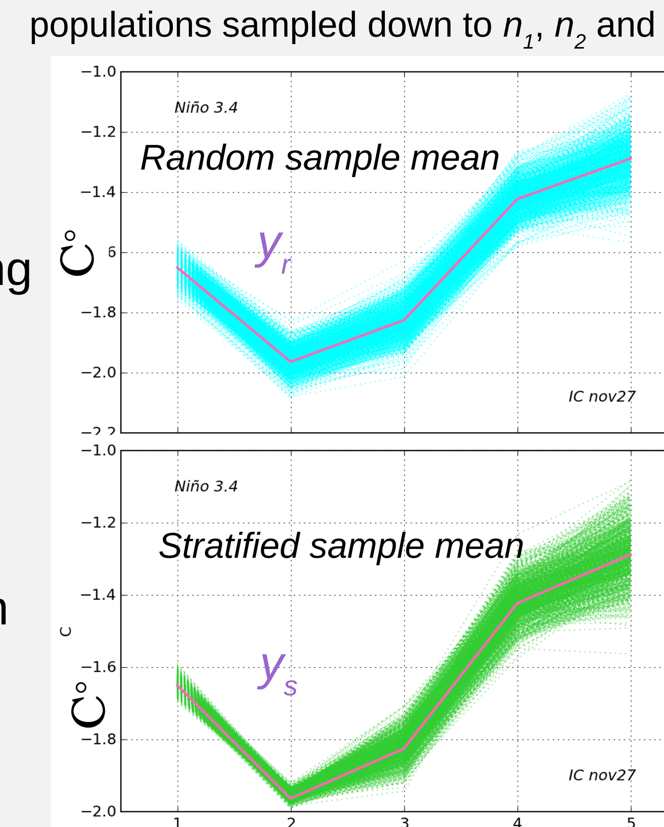
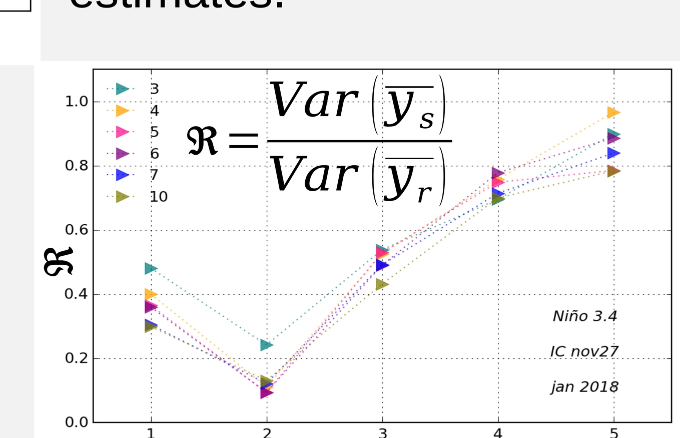



Fig. 6a. Top: 1000 estimates of the large ensemble mean by a randomly sub-sampled smaller ensemble to estimate $y_r$.
Bottom: 1000 estimates of the large ensemble mean by stratified smaller ensemble to estimate $y_s$.




$$\Re = \frac{Var(\overline{y_s})}{Var(\overline{y_r})}$$

Fig 6b. The ratio of variances $y_r$ and $y_s$ estimated for the 2[nd] lead month. $\Re$ < 1 at least for the first 5 months. Results are shown for 3-7 and 10 clusters (strata). There is little benefit from increasing the number of strata beyond 4 or 5.

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### References

Schubert Siegfried, Anna Borovikov, Young-Kwon Lim, and Andrea Molod, 2019. Ensemble Generation Strategies Employed in the GMAO GEOS-S2S Forecast System. NASA Technical Report Series on Global Modeling and Data Assimilation, NASA/TM-2019-104606, Vol. 53, 75 pp.

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